

## Chapter 16

### Ice-Related Hydrometeorological Data Collection and Monitoring

#### 16-1. Introduction

The Corps of Engineers must deal with ice problems affecting operations at Corps projects and at other locations for which the Corps has primary responsibility for responding to emergencies. In addition, effective regulation of Corps water control and navigation projects requires the collection of a wide variety of real-time hydrometeorological data from field sites, but monitoring procedures and resources are not uniform among, or even within, Corps Divisions affected by ice problems. Each District has established its own methods and priorities for collecting information or making observations to meet their needs. A number of instruments are available for both manual and automated ice observations. Manually collected ice observations use a great deal of manpower, and are costly and hazardous. They also provide only spot measurements of a process that is generally dynamic. Automatic data collection can be done around the clock, providing a continuous source of data while at the same time decreasing budgeted manpower and freeing personnel for other work. In remote sites, automated data collection is often the only option. Some Districts have independently developed their own methods of field data collection (e.g., Pomerleau 1992). However, little direct coordination has taken place among Districts in identifying instrumentation that could automate or simplify ice data collection, storage, and retrieval.

*a. Survey of Existing Data Collection Methods Employed by the Corps of Engineers.* A survey designed to identify existing and desired ice data collection instrumentation, methods, and storage, and types of ice effects, was sent to all Corps of Engineers Districts and Divisions affected by ice (Kay and White 1997). Ninety-nine survey responses were received. The three areas of Corps responsibility most often affected by ice are flood-control structures, navigation traffic, and locks. Freezeup problems predominate over breakup problems for all operations and structures included in the survey, except flood-control structures. The number of projects affected by both freezeup and breakup is equal to the number affected by freezeup alone. The physical properties rated highest by survey respondents for importance are stage and discharge, followed by air and water temperature, ice thickness, and condition of ice. Corps personnel are currently making the vast majority of ice observations from the shore or a nearby structure, such as a bridge, dam, lock, or levee, using still and video cameras. Some instruments or methods to collect data from the ice surface (e.g., the CRREL ice thickness kit, see Paragraph 16-6a) are used by a number of Districts, but they require intensive human effort. The use of DCPs is fairly common, but they are typically used to measure stage, discharge, and a few meteorological conditions. The survey results indicate that there is much potential for automating the storage and retrieval of ice data, but the willingness of observers to convert to computer storage was not gauged. Currently, ice data are predominantly stored in paper form. The information that is being stored digitally is in several different formats, including word processing programs and HECDSS, the time series data storage system developed by the Hydrologic Engineering Center (HEC 1990). A centralized data storage system is important, so Districts should strive for software uniformity as much as possible to avoid data translation problems. In the future, a fairly robust database should be set up, with the capability for GIS querying of those data included. The survey also showed that there is potential for increased use of existing instrumentation and that some new types of instrumentation, particularly remote sensing, are desired.

*b. Sources of Information on Ice Conditions.* Adequate information on ice conditions is a necessary part of an ice management program at Corps facilities. Corps Districts generally have one or both of the following objectives when documenting ice conditions as part of their river ice management activities.

(1) To analyze past ice conditions as an aid in forecasting future conditions during a given winter.

(2) To monitor current conditions during a winter in sufficient detail to allow planning of waterway operations and anticipating navigation problems.

(3) The first objective can be met using historical ground observations, aerial photographs, and satellite images. However, the most common District need is for monitoring current ice conditions along all their navigable waterways. At most navigation projects, Corps personnel already make ice observations and report them to District offices nearly every day during the winter season. The data are then available to users via computer modem. However, these ground observations are pertinent only for that portion of a waterway within sight of the observers. Ice conditions beyond that are uncertain, and yet such data for the entire waterway are required. Satellite images from current civilian satellites, which do show entire waterways, do not have sufficient spatial resolution nor can they routinely be in the hands of District personnel quickly enough to help decision-makers cope with waterway operations or ice emergencies (Gatto et al. 1987, Gatto 1988). As satellite sensors and image processing systems improve, however, future images may be provided rapidly enough and may be of sufficient resolution to be useful.

## **16-2. Existing Instrumentation and Observation Methods**

All Corps Districts maintain some level of instrumentation to observe various hydraulic and hydrologic properties, but the quantity and types of ice observations vary greatly among them. This may be a reflection of either the severity of ice problems experienced or knowledge of the importance of ice data collection. The end use of the measurement data appears to affect how “high-tech” or “low-tech” the measurement devices are. For example, stage may be visually inspected and recorded once a day in a logbook by personnel at one project location, while another individual may be interested in continuously monitoring the rise and fall of stage at multiple locations during the freezeup and breakup periods. The survey indicated that various hydraulic and ice properties are being visually observed on-site, and that the observers seem to be generally satisfied with current practices. The respondents did not indicate a desire to measure additional properties, but, unfortunately, the survey did not gauge how willing personnel would be to automate those observations already being made. The more commonly used instruments and observation methods employed by responding Districts are listed in the following paragraphs, along with some of their advantages and disadvantages. A good reference for ice data collection is the report by White and Zufelt (1994).

### 16-3. Stage Measurements

According to the survey, the hydraulic properties most commonly measured by Corps of Engineers Districts are stage and discharge. For open water conditions, discharge is usually determined from a rating curve that relates a specific discharge to a specific stage. The stage–discharge relationship for ice-affected flows is often far more complex and depends greatly upon ice conditions (Rantz et al. 1982a, 1982b).

#### *a. Manual Measurement of Stage.*

(1) *Staff Gage.* One of the easiest ways of measuring stage is to use a staff gage that is installed either permanently or temporarily, depending on needs of the users. Staff gages vary from the standard USGS porcelain-enameled iron gage with markings every 0.6 centimeters (0.02 feet) (Rantz et al. 1982a) to a wooden building stud with markings every 15 centimeters (6 inches). Permanent gages should be attached to (or painted on) permanent structures, such as bridges or drainage structures, or located in sheltered areas, such as an area of heavy vegetation, to protect them from ice and debris. Permanent gages can be installed along a river bank, but they may be heavily damaged by ice. Temporary gages can be installed during flood emergencies to measure stages in areas not otherwise monitored. These gages can be subsequently reclaimed and reused, but must be installed in the water, or an area expected to be underwater, to be effective. This could pose a very serious threat to installation personnel during an ice jam flood. The greatest advantages to the use of a staff gage are that virtually anyone can make a reading with very little training, and they can be installed almost anywhere for relatively little cost and usually require little maintenance. However, there are several disadvantages to the use of a staff gage. Stage can only be measured at the time of observation, which often means that the peak stage at a location is not measured. Measurements are limited to daylight hours, unless the gage is in a well-lit area. Flooding or poor weather conditions may make access to the gage impossible or make the gage difficult to read accurately, even with binoculars. Often, personnel requirements make frequent gage readings impossible, especially if gages are spread over a wide area.

(2) *Wire Weight Gage.* Wire weight gages (Rantz et al. 1982a) consist of a weight attached to a cable wound in a single layer around a drum (Figure 16-1). The gage is contained in an aluminum box that is mounted on a bridge. The box contains a calibrated disk that the cable passes over when it is lowered to the water surface, and a counter that records the distance that the calibrated disk moves. Stage is calculated from the counter value when the box is placed a known height above the streambed. A chain gage is similar to a wire weight gage, except that the weight is attached to a chain that passes over a pulley. As the weight is lowered to the stream surface, the chain moves along a marked horizontal gage from which the distance moved is calculated (Bureau of Reclamation 1984). Wire weight gages and chain gages have the same disadvantages as do staff gages, with the additional disadvantages that relatively few people have the training or access required to make such measurements, and that the wind can blow the weights, causing the reading to be larger than actual (Bureau of Reclamation 1984).

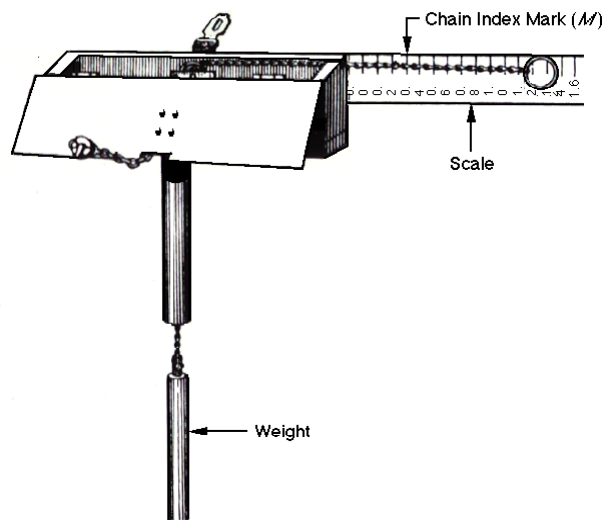
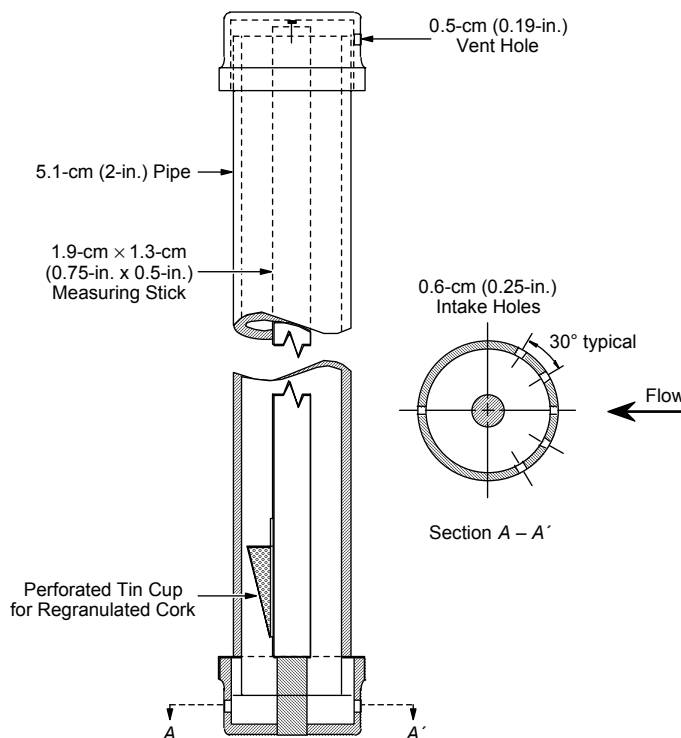


Figure 16-1. Chain gage used to measure stage (after Rantz et al. 1982a).

(3) *High Water Marks.* High water marks can be determined following a flood event, either by examination of vertical or near-vertical surfaces for evidence of the waterline, or by looking for ice scars on trees (White and Zufelt 1994). Ice scars are areas of damage to a tree trunk, usually caused by moving ice. The disadvantages of high water marks are that funding may not always be available to do the required surveys, rainfall or warm weather following an ice-related high water event can obliterate high water marks before they can be set, and additional flooding can obliterate high water marks before they can be surveyed.

(4) *Crest Stage Gage.* There are occasions when only the peak stage associated with an ice jam event is desired at a remote location. The USGS frequently uses crest-stage gages (Rantz et al. 1982a) in flood flow frequency studies to record maximum peak stages in known jam locations. These gages (Figure 16-2) are made of a galvanized pipe, with holes drilled near the bottom, that is installed in the streambed. A graduated rod or staff is placed within the pipe at a known datum. A perforated cup or cone filled with regranulated cork or similar substance is attached to the lower end of the staff. As the water level rises within the pipe, the cork is floated out of the cup, and it will adhere to the walls of the pipe and the staff at the highest level that the water reaches. The staff is removed from the gage and read as soon as the water drops to safe levels. These gages have low-cost, and reportedly good reliability and low maintenance. Keeping the water within the pipe liquid is important during winter operation, perhaps by heating the pipe or installing a solar cell at the top of the pipe to power heating coils or a small bulb.



**Figure 16-2. USGS crest stage device used to measure peak stage (after Rantz et al. 1982a).**

(5) *Maximum-Minimum Stage Gage*. Another possible maximum stage recorder would be an adaptation of a maximum–minimum stage gage described by Zabilansky et al. (1992), in which a float of some type is fitted between two washers over a 19-millimeter (3/4-inch) pipe that is installed in the streambed. During the winter, ice attaches to the float and, as the float is moved up and down by ice action or waves, the washers are pushed up and down on the pipe, recording wave maxima and minima. A similar device could be used to record maximum stage during an ice (or open-water) event. A conceptual drawing of such a device is shown in Figure 16-3. The greatest challenges to installing such a device are to design the rod to withstand the lateral and uplift forces exerted by ice and to keep the float from freezing to the rod. The use of a dark material for the float and rod would help avoid freezing. The float would require some type of spring mechanism to prevent it from sliding down the rod when stage recedes, but to also allow it to be reset every year (or after every flood, if desired). A solar collector panel could be mounted to the top of the rod, and heating coils could be put inside to help stop ice from forming. With either the gage discussed in this paragraph or the one discussed in Paragraph 16-3a(4), the stage could be read at a later date as time and weather conditions permit, so long as a flow with higher stages does not occur in the interim. One drawback is that the date and time of the peak must be estimated. Several such devices could be put into place along a relatively short stretch of river to obtain jam profiles, or a network of such devices could be used to supplement USGS gaging locations for recording the peak stages at known jam locations, since USGS gages are not always located near a jam.

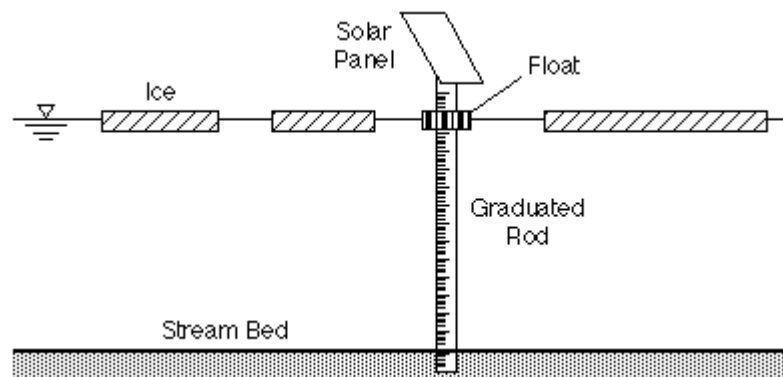


Figure 16-3. Conceptual view of maximum stage gage.

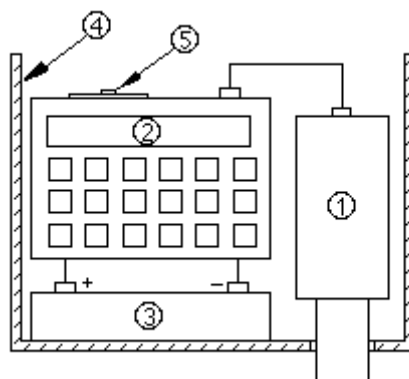
*b. Remote Measurement of Stage.*

(1) *Water-Stage Recorders.* Stage information has been remotely collected via water analog or digital stage recorders. Various types of stage recorders have been used for a number of years (Rantz et al. 1982a). One of the most common is a pen recorder with rotating drum. These instruments are reliable and accurate for recording stage and are relatively inexpensive to install and operate. However, they can suffer a number of mechanical problems that require relatively frequent checks. For example, the clock mechanism for driving the drum may not operate at the proper speed, the pen may run out of ink, or the float system may freeze in place during cold weather. The strip charts require regular visits to replace, and storage requirements for several years' worth of strip charts may become cumbersome. Stage must be read directly from the strip chart and can be read incorrectly, especially from charts with reversing pen mechanisms. The use of digital recorders is quite common in the Corps, especially at sites with DCPs, and they are often connected to a pen recorder. Automated digital recording is becoming more popular, as it avoids many of the disadvantages associated with strip charts.

(2) *Pressure Transducers.* Pressure transducers are quite versatile, as they can be installed in a variety of situations. The pressure transducers now routinely used are capable of measuring stage to within 0.01 feet (3 millimeters). They have no mechanical parts, so they do not suffer from many breakdowns. One disadvantage is that the orifice lines can clog, particularly on streams with a high silt and clay load, causing readings to be in error until the lines can be back-flushed to clear the obstruction. Telemark systems are still used at some remote sites, but the advent of DCPs has reduced the use of this remote monitoring querying method.

(3) *Ultrasonic Measurement.* Ultrasonic instruments have been used for a number of years with varying levels of success. They have the advantage over traditional water level recorders that direct contact with the water is avoided, thus decreasing the incidences of freezing and damage by water-borne debris. Ultrasonic instruments are susceptible to rapid changes in air temperature, and wind can disturb the water surface enough to disrupt the return signal (Abraham and Hall 1994). The absolute accuracy of the ultrasonic sensor is relative to its range, although resolution may be to 0.01 feet (3 millimeters). In other words, two sensors with the same range may not have the same accuracy if their relative accuracy varies, or two sensors with the same relative accuracy will not have the same absolute accuracy if their ranges differ. The capabilities

of individual sensors will vary with manufacturer and cost. It is not known how an ultrasonic sensor would perform over an ice surface. To be truly portable, the sensor, its recorder, and the power source must be self-contained in a small, lightweight package, such as that shown in Figure 16-4. The unit would need to be enclosed in a weather-tight box that could either be permanently mounted on a surface, such as the side of a bridge, or it could be temporarily hung over the side of a bridge. If the housing were permanently installed, the components within could be removed and used among various locations. A data logger and ultrasonic sensor must be selected with the expected operating climate, data requirements, and operating properties in mind.



**Figure 16-4. Section view of ultrasonic stage recorder: 1 is the ultrasonic sensor, 2 is the datalogger, 3 is the power source, 4 is the weatherproof enclosure, and 5 is the output port for downloading data to a laptop or telephone.**

(4) *Radar Measurements.* Recently, the measurement of stage with a millimeter-wave (MMW) frequency modulated–continuous wave (FM–CW) radar has been explored. The system deployed by Yankielun and Ferrick (1993) could be mounted from a bridge and used to acquire, process, store, and display river stage data at time intervals ranging from 1 to 60 seconds around the clock. Their system had a maximum range of 11.46 meters (37.6 feet). With the proper siting, this system could also measure ice thickness (see Paragraph 16-6). The greatest drawback to the use of either ultrasonic or radar systems is that they measure distance to the first surface encountered, so that when a stream is ice covered, the distance to the ice surface would be measured, rather than the distance to true water surface. If true stage were desired, it would be necessary to maintain an area of open water below the instrument. The system described by Yankielun and Ferrick includes a radar front end, a function generator, a dynamic signal analyzer, and a 12-bit analog-to-digital converter internal to a laptop computer. The radar front end consists of a voltage-controlled oscillator (VCO), waveguide components, transmit and receive antennas, a mixer, and an audio amplifier. A schematic of the system is shown in Figure 16-5. Signal processing is probably the biggest obstacle to fielding this device. If measured stage for only one event is desired, processing could be done after the entire event has been recorded, but random or regular querying of stage is more complicated. An instantaneous value of stage could be substantially in error if waves, ice, or debris happen to be passing through the radar scan at the time of measurement. A typical procedure would be to sample stage for the period of time necessary for adequate accuracy, processing the data, time-averaging the stage values, and transmitting the

computed value. This may be difficult if the DCP is in a random report mode. Another option would be to sample stage continuously between DCP queries, process the stage data, and continuously update the time-averaged stage. The average stage and maximum and minimum stage could then be transmitted (provided the DCP has enough free channels) and the whole cycle would start over again. Signal processing requires a fairly robust system to process and continuously update values, and a fairly decent signal-processing algorithm needs to be developed to account for false values (e.g., if a bird or large debris passed through the radar beam).

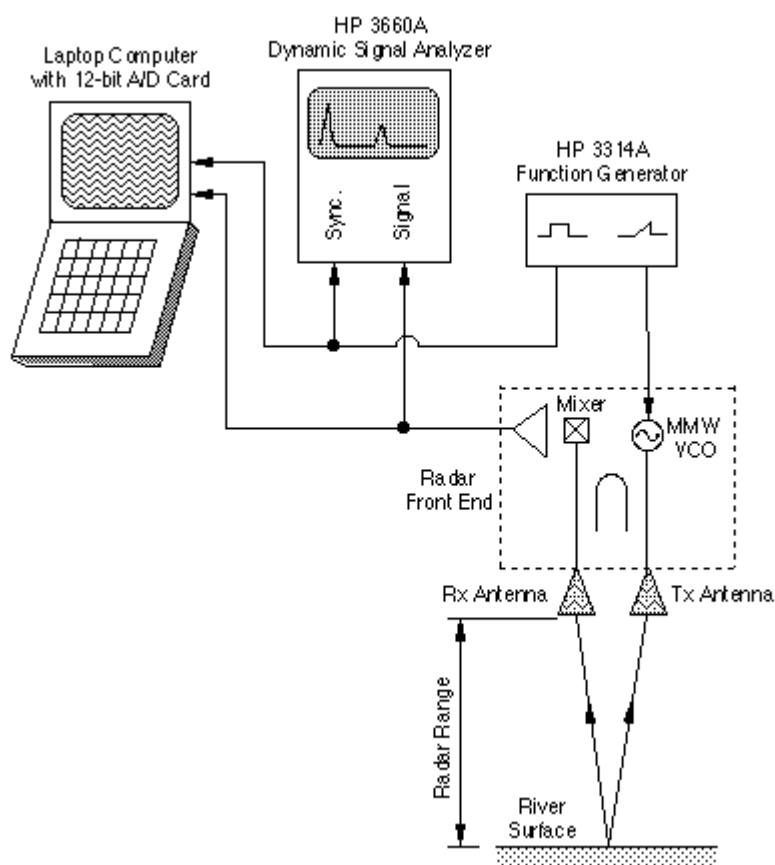


Figure 16-5. Schematic of MMW FM-CW used for velocity determination.

#### 16-4. Discharge

Direct discharge measurements are generally made by the USGS (Rantz et al. 1982a), although some Districts maintain the capability to make discharge measurements at selected locations. Discharge measurements collected under an ice cover are generally thought to have greater uncertainty than discharge measurements made in open water at the same location (Cobb and Latkovich 1986). Ice does not even have to be present to affect the stage–discharge relationship; decreases in water temperature apparently affect bed roughness (Colby and Scott 1965).

*a. Standard Discharge Measurements.* The USGS uses Price-type vertical shaft meters to measure discharge. Because the accuracy of Price meters can be affected by ice or cold water

(Rantz et al. 1982a), the USGS has used the modified yoke Price-type winter meter as the standard for discharge measurement through an ice cover since 1988. The use of solid plastic rotors reduce rotor plugging during frazil ice conditions (Wagner 1994). The current USGS standard method of discharge measurement in ice-covered streams (Rantz et al. 1982a) requires the drilling of holes in the ice through which the current meter is immersed (unless open water exists relatively near the gaging station). The use of the ice surface as a working platform can lead to concerns for personnel safety.

*b. Estimating Discharge from Stage-Discharge Curve.* Guidance is available for preparing discharge-frequency curves for open-water conditions at gaged sites (e.g., Hydrologic Engineering Center [HEC] 1992, Water Resources Council 1982). Unfortunately, less attention has been given to the case where ice effects are important. In ice jams, gages may be badly damaged and made useless. In addition, because ice jams often cause high stages at relatively low discharges, the traditional discharge-frequency curve is not appropriate and a stage-frequency curve must be constructed. Developing an ice-affected stage-frequency curve brings additional difficulties. For example, ice jams are unstable at high discharges, so they may only affect a portion of the stage-frequency curve and some stages reported to be ice-affected may actually be open-water stages. Length of record, the major obstacle encountered in open-water flood frequency analyses at gaged sites (Greis 1983), is exacerbated for ice-related events, which are generally much less frequent than open-water events. They have even smaller sample sizes. When a mixed-population analysis is required, a search of USGS archived records is the best source of ice information needed to develop peak stages during ice-covered periods.

*c. Near-Real-Time Discharge Estimates.* Some USGS offices maintain separate rating curves for open-water and ice-covered flow, but, typically, the USGS has not corrected the daily discharges for ice effects until after ice out, using the hydrographic and climatic comparison (Walker 1991). Walker (1991) concluded that analytical methods could be better than the subjective hydrographic and climatic comparison, but recommended further refinement and investigation. Additionally Walker (1994) suggests that a method he calls the “first-visit complete-profile” be used nationwide to improve the accuracy of discharge measurements under ice-covered conditions. Wagner (1994) notes that, during the work of Melcher and Walker (1992) in Iowa in the 1987–88 season, a computer program was developed that allowed for daily discharge adjustments via computer monitor, based on other nearby weather data and discharge hydrographs. Holschlag et al. (1997) developed a method for predicting real-time ice-affected discharge through application of an extended Kalman filter to measurements of stage and air temperature. This model was developed using data for two ice-affected gages (St. John River at Dickey, Maine, and Platte River at North Bend, Nebraska), but has not yet been implemented.

*d. Potential Radar System for Discharge Measurement.* It may be possible to combine a short-pulse radar and MMW FM–CW radar to make a discharge measurement device. The MMW FM–CW radar is capable of measuring ice velocity, while the short-pulse radar can profile the channel bed if it is operated at a low enough frequency. If ice velocity could be correlated to the average stream velocity below it, discharge could be determined by taking the point measurements of depth, multiplied by ice velocity, corrected to an average velocity. This instrument could be mounted on a vehicle and driven over bridges, or it could be mounted on an aircraft flying sections across the river. Some type of GPS unit could be used to determine cumula-

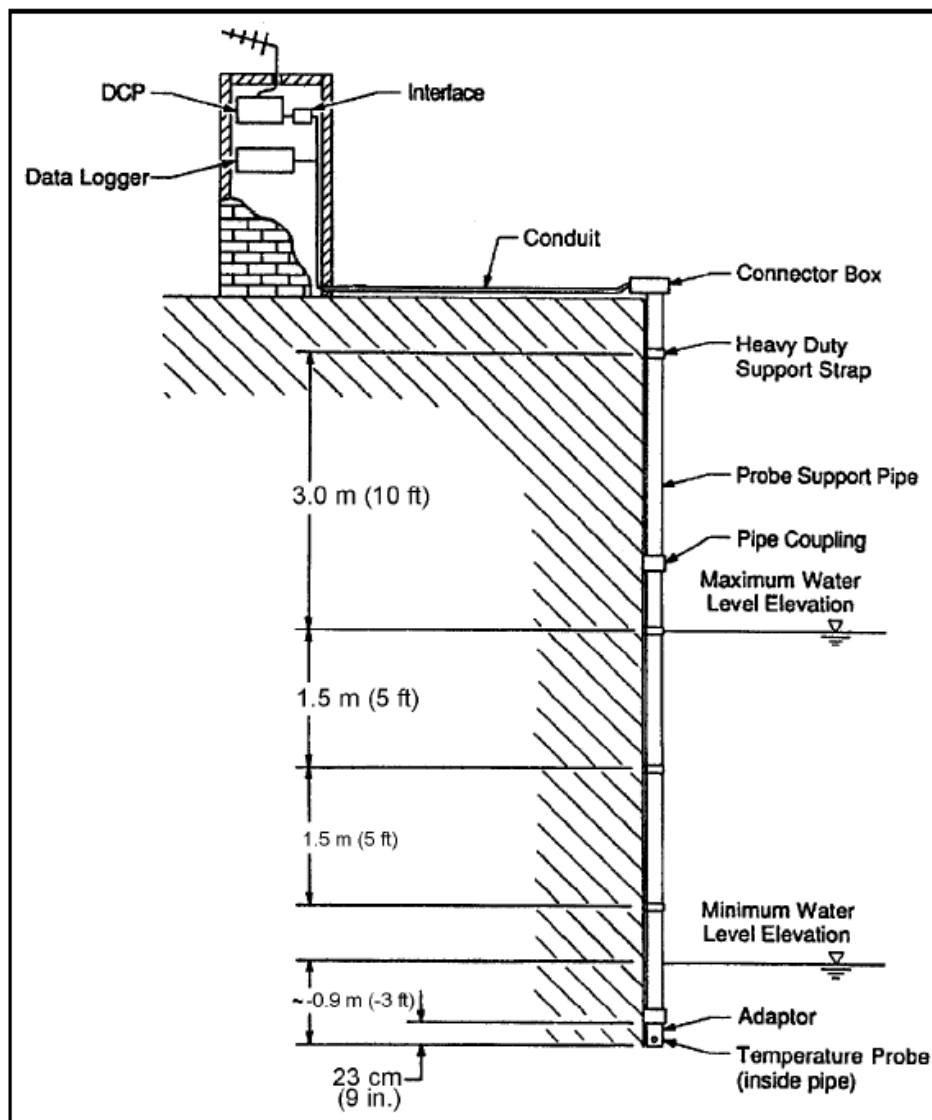
tive distance across the stream as the radars collect data. Two constraints on this idea are operating within the range of the radar units and determining whether the FM–CW system can accurately determine ice velocity while in motion itself. Data processing would be another constraint on such a system. Several years of work will probably be required to make such a system workable.

*e. Potential Discharge Measurement Using Acoustic Velocity Meters.* Wagner (1994) states that the USGS and Environment Canada have both demonstrated that acoustic velocity meters (AVM) have potential for collection of stream flow data. AVMs have been successfully used to collect line velocity between transducers, and both agencies plan to continue to evaluate AVMs. Acoustic flow meters are already in fairly widespread use; one example of their use by the Corps would be for discharge measurement in a power plant penstock to detect decreases in flow caused by frazil buildup on trash racks. However, to use an AVM in the field for stream flow measurement will require a great deal more work, especially in adjusting line velocity to average channel velocity. Another problem is that the acoustic signal used by an AVM for stream flow measurements can be disrupted during periods of slush-ice flow. If the problems with this instrument can be worked out, and it can be permanently installed at a site, it holds great potential for continuously measuring stream flow in real-time.

## 16-5. Air and Water Temperature

*a. General.* Air and water temperature are relatively easy to measure remotely, but some difficulties are still encountered. Air temperature is almost always collected at project sites using a mercury thermometer or some type of digital thermometer, or temperatures are obtained from the nearest National Weather Service site. As with any other type of instrument, a thermometer must be placed correctly to obtain a good reading. Accuracy to the nearest degree is often all that is needed for air temperature. Such is not always the case with water temperature measurements. Frazil ice forms when water supercools below the freezing point by only a few hundredths of a degree (Ashton 1986). However, if the temperature measurement device is only accurate to the nearest degree, water temperatures of nearly 0.5°C (warm enough to melt ice) and –0.01°C (supercooled) will both register as 0°C. When estimates of frazil ice production are needed (e.g., estimating when heavy frazil ice production may begin to affect navigation traffic, or when river intake structures might be affected), an instrument capable of reading to the nearest 0.01°C may be needed.

*b. Thermistors.* Typically, a glass-bead thermistor is used when very precise temperature measurements are needed. Generally, thermistors are used in conjunction with a digital multimeter. They can be permanently installed and connected to a data logger or DCP for recording temperature data. When connected to a DCP, a voltage divider circuit that converts resistance to voltage is needed. A good reference for permanent thermistor installation guidelines can be found in EM 1110-8-1(FR). A typical installation is shown in Figure 16-6. Generally, thermistors are paired within a probe to provide backup. Each thermistor in a probe is hand-made and must be individually calibrated.



**Figure 16-6. Typical water-temperature measurement system.**

- (1) The resistance of the calibrated thermistor is used in the Steinhart-Hart equation:

$$T = \frac{1}{A + B \ln R + C (\ln R)^3} \quad (16-1)$$

where  $A$ ,  $B$ , and  $C$  are the thermistor constants (typically 8 significant figures),  $R$  is the measured resistance, and  $T$  is temperature in Kelvins. Thermistors are theoretically capable of a temperature accuracy within  $\pm 0.01$ – $0.02^\circ\text{C}$ . The thermistor probe support pipe is typically installed on a wall or pier in contact with the moving river water rather than in locations such as gage wells, locks, or other areas where the water may stand for long periods and freeze. The location should be protected from direct impact of drift and ice floes; the downstream sides of piers, cells, piles, pile dolphins, and ladder accessways, and recesses in walls parallel to the river are acceptable. A

petrolatum-polyethylene gel-filled cable having a solid copper tape shield with three-pair 19-AWG conductors and a polyethylene jacket is recommended for connection to the thermistor probe. Cable expected to remain dry may be more flexible, such as a three 18-AWG, twisted, shielded pair with drain wire and polyvinyl chloride (PVC) outer jacket. Generally, a DCP can measure only voltages. Thermistors, however, change resistance in response to changing temperature. The DCP interface, therefore, is a simple voltage divider circuit that converts the thermistor resistance to a voltage. The interface is a rectangular box that is typically installed immediately adjacent to the DCP. Analog inputs to DCPs with scaling resistors should be avoided or the scaling resistors should be removed.

(2) Figure 16-7 shows a schematic diagram of the wiring of the interface box and the connections to the temperature probe and the DCP. The relation below (Equation 16-2) can be used to determine the resistance of a thermistor ( $R_i$ ) in this configuration:

$$R_i = (10,000) \frac{V_i}{V_o - V_i} \quad (16-2)$$

where  $V_i$  is the measured voltage across the thermistor, and  $V_o$  is the excitation voltage applied to the divider circuit. The applied voltage across the thermistor is kept low by the use of a diode. This is done to keep the electrical current in the thermistor to a minimum to prevent self-heating. The relatively large offset currents that may be introduced into the voltage divider circuits by the circuitry of the DCP itself result in an inaccurate voltage measurement across the thermistor. To correct for this, the voltage across a reference resistor, with a known stable resistance, is measured along with the voltage across the thermistor.

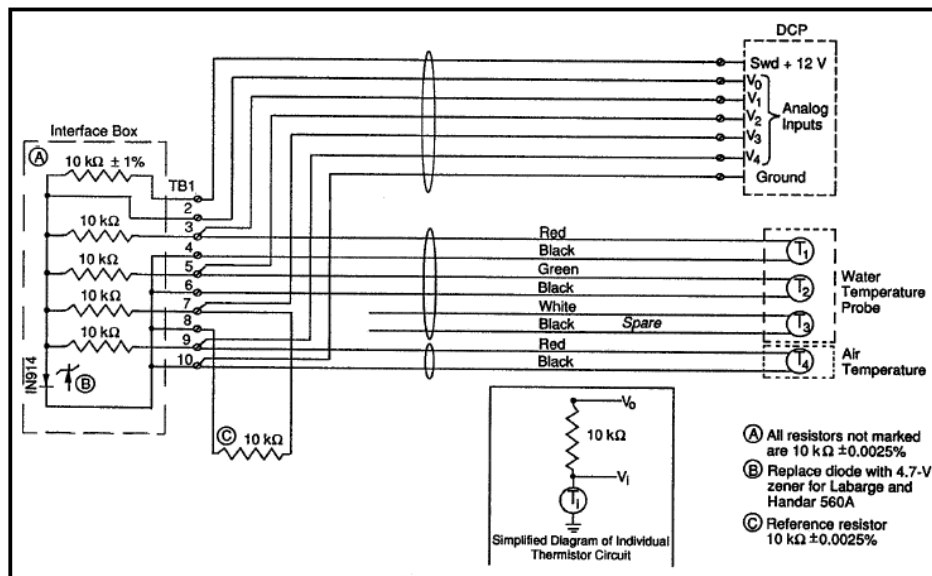


Figure 16-7. Schematic wiring diagram of DCP interface box.

(3) The measured voltage across the reference resistor  $V_f$  can then be used to calculate each thermistor's resistance by

$$R_i = \frac{(10,000) V_i}{2V_f - V_i} . \quad (16-3)$$

The DCP manufacturer's input and output impedance specifications must be known and considered by competent electronics personnel for the proper design of the DCP interface box to ensure a trouble-free overall installation.

## 16-6. Ice Thickness

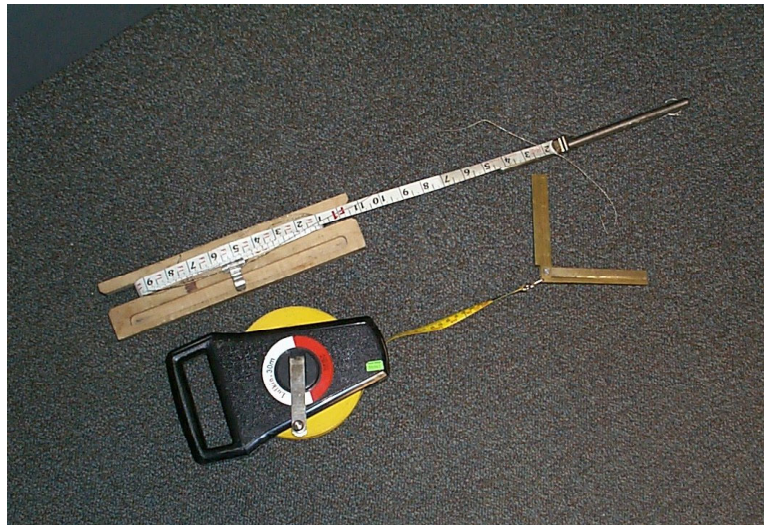
Ice thickness is currently most frequently measured either by drilling through the ice cover and measuring the thickness or by visual inspection from the shore or other vantage point. The shortcomings of both methods were pointed out earlier. Several other techniques have been used in this and other countries (Adams et al. 1986) that also require the observer to go out onto the ice or for the instrument to make physical contact with the ice. Fortunately, there has been considerable research into remote sensing of ice thickness and advances in instrumentation continue that will likely allow field implementation soon.



**Figure 16-8. Standard CRREL ice thickness measuring kit.**

*a. Manual Ice Thickness Measurement.* The standard CRREL ice thickness kit (Figure 16-8) contains a two-part iron bar used to test the ice for safety, an auger with carbide-tipped bit and bit brace for drilling holes, extension rods to increase the depth to which holes can be drilled, and a device to measure ice thickness. A small diameter auger is preferred because holes can be drilled faster, but a minimum diameter of 5 centimeters (2 inches) is recommended if velocity measurements are desired. Thickness is measured using a tape equipped with a hinged weight at the end (Ueda 1983). The weight and tape is lowered through the hole, usually until the weight hits bottom so that total depth of flow is known. The tape is then pulled upward until the weight

encounters the ice bottom and catches on the ice. It is then read so that the thickness is known. The measurement can be complicated if frazil is present underneath the ice surface, but, with a little practice, the observer can differentiate between the frazil and solid ice. If frazil is present, both the depth to the bottom of the frazil and the bottom of solid ice should be recorded. After the tape is read, the weight is hinged, or folded, and pulled back up through the hole (Figure 16-9). This method is relatively quick and accurate, but it poses risks for individuals going out on the ice cover. Another disadvantage is that only a solid ice cover strong enough to support the weight of the observers can be measured; floating frazil or very thin ice cannot be measured. The thickness of an ice jam could be measured in this way, but unless the jam is grounded or frozen in place, it would be highly inadvisable to attempt such a task because of safety reasons.



**Figure 16-9. Ice thickness measuring devices.**

*b. Thickness Estimation Using Electrical Conductance.* Sherstone et al. (1986) report on the use of “hot-wire” resistance gages to measure ice thickness in the MacKenzie Delta. The gages are installed after the initial formation of the ice cover. An 18-AWG chrome A resistance wire of known length is suspended from a platform above the ice surface through a hole drilled in the ice. The resistance wire is weighted on the bottom. A second, insulated, wire is connected to the bottom of the resistance wire. Once the hole refreezes, ice thickness can be measured by applying a current to the resistance wire, heating it, and raising the wire until the weight hits the bottom of the ice thickness. The ice thickness can then be determined by measuring the amount of resistance wire remaining above the surface. This method has the same disadvantages as the drilling method described above, with the added disadvantage that the wires can break.

*c. Visual Estimates of Ice Thickness.* Visual estimates of in-place ice thickness are highly subjective and large errors can be made. An indirect measurement of ice thickness can be made after the ice cover has broken up, when pieces of the broken ice cover that remain on shore can be measured. Observation must take place shortly after breakup, before warmer weather or rain can significantly reduce thickness. Ice jam thickness is often estimated on the basis of the height of ice shear walls, if they remain, after an ice jam releases. While these indirect methods of

thickness measurement are helpful for future use, they are not applicable for making real-time measurements of thickness.

*d. Pressure Transducer.* Ford et al. (1991) report on the development and field testing of a floating drogue equipped with a pressure transducer and radio transmitter to measure ice thickness beneath ice jams. The drogue is released into the water upstream from the jam and floats downstream under the ice cover. The radio transmitter in the drogue reports the hydrostatic pressure at the top of the drogue, which allows jam thickness to be estimated. The position of the drogue can be estimated from shore through the use of loop antennas. Two drawbacks are that the drogues may become stuck within the jam, and the speed and trajectory of the drogue through the jam cannot be controlled. However, satisfactory results were obtained in the initial field testing, and the method holds promise for the future.

*e. Radar.* Radar systems have been used for various kinds of geophysical work for years, including the measurement of sea and freshwater ice thickness. Radar, in theory, detects ice thickness by determining the distance to the air/ice interface and to the ice/water interface; then, one is subtracted from the other and the difference is the ice thickness. The two most successful types of radar have been short-pulse (or impulse) and the millimeter-wave frequency-modulated continuous-wave (MMW FM-CW) systems (Yankielun 1992). Both are currently used by researchers at CRREL, and have the advantages and disadvantages discussed below.

(1) *Short-Pulse.* Short-pulse systems have been used for a number of years. As overall radar technology has grown, the ability to detect thinner layers of ice has increased. However, the best resolution of thickness to date has been about 10 centimeters (4 inches), which is about twice the minimum thickness for safe transit by one individual on an ice sheet (CRREL 1986). Riek et al. (1990) state that it is theoretically possible, under favorable conditions, to measure thicknesses of 3–4 centimeters (1–2 inches), using appropriate signal-processing algorithms. While units were originally developed and tested on the ice surface, most recent activity has centered on the use of the unit suspended from a helicopter. The use of radar from a helicopter has allowed long extents of river ice to be profiled in a relatively short time. The area “illuminated” by the radar unit for measuring ice thickness depends upon height of the antennae above the ice surface and the velocity at which the aircraft is moving (Arcone and Delaney 1987). The use of a global positioning system (GPS) unit in conjunction with the radar system is required for tracking movement in the horizontal plane. The GPS unit could be set up to continuously query position or to determine position only on user demand, depending on the needs (and data storage capability) of the observer. One limitation of the short-pulse system, besides minimum detectable thickness, is difficulty in the measurement of frazil and brash ice thickness, and ice jams. The irregular surfaces of brash ice and ice jams scatter the radar signal, and the high water content of frazil attenuates it heavily. Daly and Arcone (1989) attempted to indirectly measure the thickness of a brash ice jam by measuring the mean height of freeboard above the water surface using a short-pulse radar from a helicopter. They accomplished this by measuring the weak, scattered signal from the brash ice pieces and the strong signal from the water surface. They concluded that it would be possible to determine the relative changes in brash depth, but more accurate absolute thickness determination would require some type of empirical adjustment for brash ice porosity, thickness, and refractive index. The presence of frazil (and brash) ice can be detected by radar at high power and low frequency, but this results in a loss of resolution of the

ice thickness measurement (Arcone and Delaney 1987). In spite of this, Ismail and Davis (1992) report measuring the thickness of a 7-m-thick ice jam from the ice surface in New Brunswick using short-pulse radar. Another limitation of this radar system is that interpretation of the data currently requires highly skilled and experienced personnel (Dean 1981). Considerable work has gone into automating signal processing, but, currently, the signal is processed after the data are collected. If short-pulse radar is to be useful in the field, the system would need to process the signal and display ice thickness in real-time (or near-real-time), as well as to be able to store the collected information for later use. The collection of data requires a great deal of storage; as an example, O'Neill and Arcone (1991) point out that with a helicopter speed of 2 meters/second (6.6 feet/second) and a digitization rate of 25,000 samples/second, approximately 12.5 MB of data are produced per kilometer of survey.

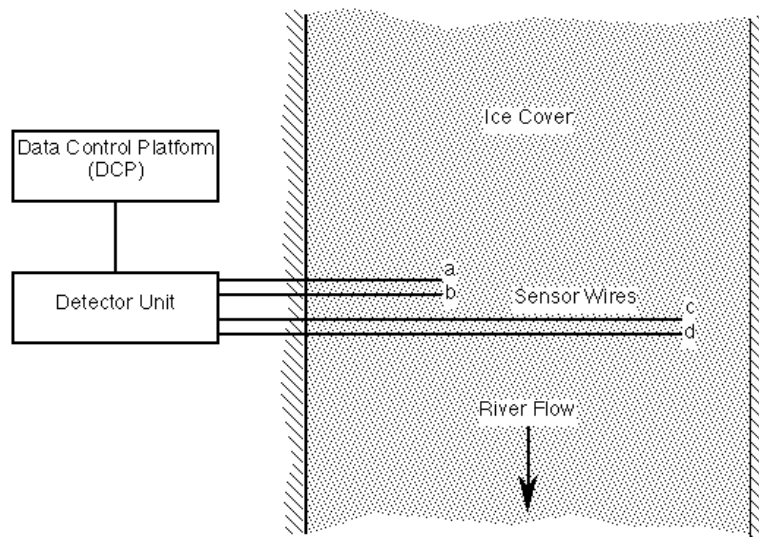
(2) *Millimeter-Wave Frequency-Modulated Continuous-Wave.* The MMW FM-CW radar system suffers from most of the disadvantages of the short-pulse radar, but it can do things that the short-pulse radar unit cannot. The FM-CW system cannot penetrate water so it is unable to determine ice thickness once water begins to pool on the surface. However, this could be used to advantage if it were used to determine when a previously stable ice cover is nearing breakup. Because of its shorter wavelength, the MMW FM-CW system has been capable of profiling much thinner ice than has the impulse radar system. It can be mounted from a helicopter for ice thickness profiling (Yankielun et al. 1993), and research continues on mounting it from a fixed wing aircraft. This system is likely to be less expensive than the impulse radar system, as the radar front end can be found at most well-supplied electronics stores for under a few hundred dollars. Toikka (1987) also discusses the use of an FM-CW radar for measuring ice thickness. Cost is likely to be a major factor in bringing any radar system on-line in the near future. Yankielun (1992) estimates the cost of his FM-CW radar system at approximately \$57,000 if all new components were purchased off-the-shelf. Even if the radar front end can be purchased for a few hundred dollars, a signal processing unit that costs several thousand dollars is still necessary.

f. *Upward Looking Sonar.* Rossiter and Crissman (1994) mention the possibility of using upward-looking sonar to determine ice thickness. The sonar sensor would need to be anchored to the riverbed below a level at which ice could not cause damage. This system would only be capable of point measurements and thus could be used to estimate ice speed but not direction.

g. *Electromagnetic Induction.* Another way in which ice thickness measurements have been made is electromagnetic induction methods. CANPOLAR (1985) reports on several manufacturers with electromagnetic induction instruments used for measuring ice thickness from the ice surface. They also state that electromagnetic induction methods appear to be the most promising technology for remote measurement of ice thickness, although a great deal of work is needed for a usable device. Arcone et al. (1987) report on the use of magnetic induction to detect frazil deposits. They report that the magnetic induction method would work best on frazil with low water content and work less well on shallow streams with bottom sediments, such as gravel or gravelly sand that could be confused with frazil. So far, magnetic induction instruments have not been used from an airborne platform.

## 16-7. Ice Movement and Velocity

a. *Ice Movement.* Corps personnel normally monitor the movement of river ice visually to determine when and where breakup may be occurring or where moving ice may affect navigation traffic or lock operation. Little automation of ice movement monitoring exists at the District level at this time. A remote means of monitoring ice movement has recently been developed by CRREL researchers and has been used in the field (Zufelt et al. 1995). A schematic of the ice motion detector is shown in Figure 16-10. Wires embedded in the ice are connected to the detector unit, which is then connected to a DCP, phone, or some other device capable of transmitting a signal. When the ice cover begins to break up and move, the wires are broken. The detector transmits one signal when the wires are whole, and different levels as each wire is broken. The multiple wire configuration provides redundancy to reduce the likelihood of a false alarm and to monitor more width of the river against breakup. The detector unit can be set up to handle complex situations, as described in Zufelt et al. (1995), or it can be as simple as a burglar alarm with built-in dialer attached to a telephone. The greatest advantages of the ice motion detector system are that it works around the clock at a minimal cost, typically only takes a few hours to install, and is simple to operate. One disadvantage is that the wires must be installed in the ice every year. Rachuk and Rickert (1986) describe the use of a similar concept, an array of sensors embedded in the ice, in Canada on the Athabasca River. The MMW FM-CW radar system described earlier can also detect ice motion, as well as ice velocity, with slight modification (Ferrick et al. 1995). It can be used in the period before a stable ice cover forms, unlike the unit developed by Zufelt et al. (1995).



**Figure 16-10. Schematic of ice motion detector connected to DCP. The detector returns different levels of response depending on whether wires a, b, c, or d (or various combinations) are intact, allowing the user to determine the extent of ice cover breakup and movement.**

*b. Ice Velocity.* Ice velocity, while not typically monitored, has been measured by a variety of remote methods. It can be estimated by measuring the time required for an ice piece or other small particle takes to traverse a given length of river using a stopwatch and taped distance along the bank. Prowse et al. (1986) report a similar method used by the Hungarian Water Conservation Bureau in a reference grid is set up at a particular location in the river through the use of temporary markers in the water and fixed markers on land. Time-lapse photography obtained during freezeup and breakup is compared to the reference grid to estimate surface ice velocities and ice concentration (Figure 16-11). Prowse et al. also tested the use of false-parallax and image-digitizing photogrammatic techniques with large format cameras to determine ice velocities and found them to be quite accurate for surface velocity determination, but limited in value for conversion to ice discharge estimates. Images from 35-mm cameras were found to be adequate and much less expensive. Prowse and Demuth (1991) used a theodolite to track the movement of ice pieces to measure velocity. Ferrick et al. (1991) videotaped markers on an ice cover before and during breakup to obtain information on ice velocities.

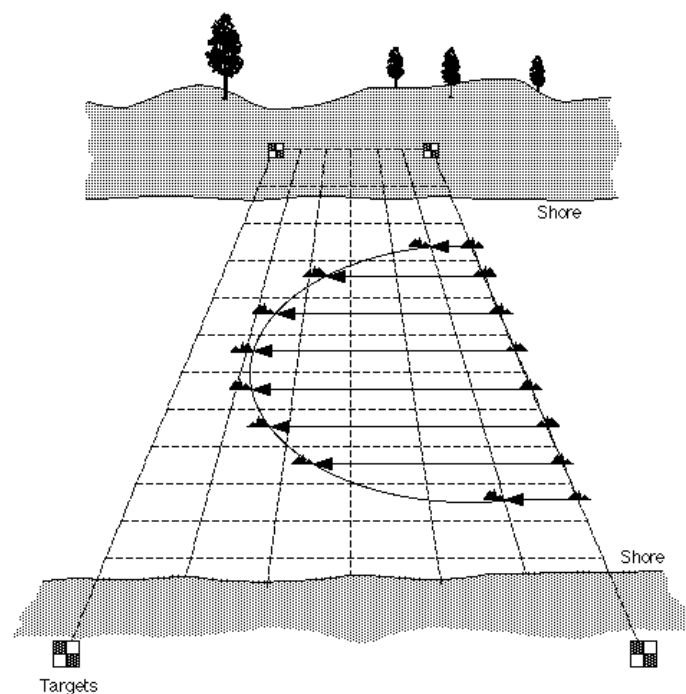


Figure 16-11. Photographic grid method for determining ice velocity and concentration.

## 16-8. Ice Extent and Concentration

*a. Aerial Ice Extent.* Areal ice extent may be monitored from a single vantage point or series of vantage points, but the accuracy of observer estimation decreases with increasing distance from the observer. The areal extent of ice can also be observed from aircraft and then documented by 35-mm still or digital photography, video, or by an individual marking the ice cover

locations on a map. Evans and Mata (1984) provide useful guidance for obtaining hand-held aerial photography. Aerial videotapes are more convenient to take than overlapping hand-held photographs, if continuous coverage of a waterway is required, and are less expensive than vertical 23 × 23-centimeter (9 × 9-inch) aerial photographs. Guidance can be found in Meisner and Lindstrom (1985), Meisner (1986), and Maggio and Baker (1988). Table 16-1 compares hand-held aerial photography and aerial videotaping. Bank-to-bank coverage should be maintained while videotapes are being taken. Widths of the waterway to be taped should be used to determine the flying heights and focal lengths required to provide bank-to-bank coverage and to determine the maximum aircraft speed to avoid image blur caused by forward image motion and aircraft vibration (see Table 16-2). The best positioning for a hand-held camera or video camera to document the ice from aircraft is straight down, as is done with aerial photographs made for mapping. Oblique views are also very useful but do not readily allow for scaling of features from the film. The pros and cons of camera use are discussed further in USACE (1990).

**Table 16-1**  
**Two Methods for Monitoring Ice Conditions on Navigable Waterways**

Method	Equipment	Costs*	Advantages	Disadvantages
Hand-held aerial photographs	35 mm camera	\$300	Good resolution Different films can be used Low costs, once initial purchases are made Supplies and equipment readily available Camera systems are portable and flexible No extensive training required; most everyone is familiar with cameras Photographer can select targets	Can't take photos during inclement weather Takes a few hours to get slides or prints Ice thickness not obtainable; best guess only Snow-cover obscures ice Quality of photos unknown until they are developed
	Color film for slides or prints	\$3–\$8/roll for slides, \$7 for prints		
	Maps for locating photos in flight	\$1.50 each		
	Fixed-wing aircraft** (e.g., Cessna 172)	\$60–\$80/hr		
Aerial videotapes	Camera for ½ in. VHS or Beta, ¾ in. U-matic	\$1200–\$5000	Continuous view of river Immediate availability of tapes Operator sees image during acquisition; could correct problems in flight Low cost No extensive training required; familiar to many people Playback technology widely available Can get slides and prints from tapes Supplies and equipment readily available Tapes can be reused Videographer can select targets, if taking obliquely	Lower resolution than photographs but sufficient to differentiate ice types Can't take tapes during inclement weather Ice thickness not obtainable; best guess only Snow-cover obscures ice
	On-board monitor	\$ 600		
	Video recorders	\$2500 (½ in.), \$5000 (¾ in.)		
	Camcorder (VHS)	\$1600–\$2200		
	High grade color videotapes (T-120)	\$7/tape		
	Maps for locating tapes in flight	\$1.50 each		
	Fixed-wing aircraft** (e.g., Cessna 172)	\$60–\$80/hr		

\* Costs will vary; these are simply estimates (1988 dollars).

\*\* Helicopters can be used but cost more per hour.

**Table 16-2**  
**Aerial Video Coverage Versus Pixel (Picture Element) Size, Altitude, and Aircraft Speed (Based on 2/3-inch Video Format)**

SI Units								
Coverage (m)		Effective Pixel Size* (m)	Altitude (Feet Above Ground) Required for Various Lens Focal Lengths					Maximum Aircraft Speed** (km/h)
Width	Length		6.0 mm	8.5 mm	12.5 mm	16.0 mm	25.0 mm	
152	114	0.6	104	147	216	277	433	101
305	229	1.2	208	294	433	554	866	203
457	343	1.8	312	442	650	831	1,299	304
610	457	2.4	416	589	866	1,108	1,732	406
762	572	3.0	520	736	1,082	1,385	2,165	507
914	686	3.7	623	883	1,299	1,663	2,598	610
1,067	800	4.3	727	1,031	1,515	1,940	3,031	711
1,219	914	4.9	831	1,178	1,732	2,217	3,464	813
1,524	1,143	6.1	1,039	1,472	2,165	2,771	4,330	1,015
1,829	1,372	7.0	1,247	1,766	2,598	3,325	5,195	1,218
2,134	1,600	8.2	1,455	2,061	3,031	3,879	6,061	1,421
2,438	1,829	9.4	1,663	2,355	3,464	4,433	6,927	1,624
3,048	2,286	12	2,078	2,944	4,330	5,542	8,659	2,031
3,658	2,743	14	2,494	3,533	5,195	6,650	10,391	2,437
English Units								
Coverage (ft)		Effective Pixel Size* (ft)	Altitude (Feet Above Ground) Required for Various Lens Focal Lengths					Maximum Aircraft Speed** (knots)
Width	Length		6.0 mm	8.5 mm	12.5 mm	16.0 mm	25.0 mm	
500	375	2	341	483	710	909	1,420	55
1,000	750	4	682	966	1,420	1,818	2,841	109
1,500	1,125	6	1,023	1,449	2,131	2,727	4,261	164
2,000	1,500	8	1,364	1,932	2,841	3,636	5,682	219
2,500	1,875	10	1,705	2,415	3,551	4,545	7,102	274
3,000	2,250	12	2,045	2,898	4,261	5,455	8,523	329
3,500	2,625	14	2,386	3,381	4,972	6,364	9,943	384
4,000	3,000	16	2,727	3,864	5,682	7,273	11,364	439
5,000	3,700	20	3,409	4,830	7,102	9,091	14,205	548
6,000	4,500	23	4,091	5,795	8,523	10,909	17,045	658
7,000	5,250	27	4,773	6,761	9,943	12,727	19,886	767
8,000	6,000	31	5,455	7,727	11,364	14,545	22,727	877
10,000	7,500	39	6,818	9,659	14,205	18,182	28,409	1,097
12,000	9,000	47	8,182	11,591	17,045	21,818	34,091	1,316

\* Effective pixel size based on 258 pixels per format width.

\*\* To avoid forward image motion blur if not using shuttered camera or forward image compensation.

*b. Ice concentration.* Ice concentration (i.e., how much of the channel is covered by floating ice pieces) is estimated from visual observations from a structure, shore, or aircraft. Estimating an ice concentration suffers from the same disadvantages as estimation of areal ice extent. An additional disadvantage is that the estimate is highly subjective. Two individuals viewing the same event may interpret the concentration of ice pieces as being quite different, even if given

guidelines demonstrating the differences between different levels of concentration. For quantitative measurements, a “frame-grabber” to capture and digitize videotaped images of moving ice can be used (Bjerke 1991). Using a computer algorithm, the digitized image is rotated to provide a vertical view, from which ice piece size and concentration can be determined.

(1) *Video*. Rossiter and Crissman (1994) describe the use of low-light-level television (LLLT) video cameras and marine radar for measuring ice concentration on the Upper Niagara River for the New York Power Authority and Ontario Hydro. Each method had a limited range of observation (less than 3 kilometers [2 miles]). The LLLT cannot be used in dark or snowy conditions and the imagery must be interpreted subjectively. Software must be developed to allow the marine radar to differentiate between moving and stationary ice, and the system was described as being more expensive than alternative methods. They also state that systems capable of observing an ice cover can also be used to estimate ice speed, if properly calibrated and if trackable ice features are present. The method described by Bjerke (1991) previously also shows promise for daylight measurements of ice concentration.

(2) *Satellite Imagery*. Another method of monitoring ice concentration, satellite imagery, currently has limited potential, but as satellite capabilities improve, so will the potential for monitoring ice conditions. Gatto et al. (1986) and Gatto (1988) attempted to describe ice conditions on the Ohio, Allegheny, and Monongahela Rivers and Illinois Waterway over a 13-year period using available Landsat images. There are disadvantages to using Landsat imagery: the number of usable images is limited by the long satellite repeat cycle and frequent cloud cover, river ice is not always apparent because the instantaneous field of view of the satellite sensors is sometimes insufficient to detect the amount and type of ice present, and computer analysis is necessary to evaluate the additional information collected by Landsat sensors (which “see” more than a standard camera does). McGinnis and Schneider (1978) discuss the use of Landsat, NOAA, and GOES satellites. NOAA and GOES provide much coarser resolution but offer daily extent, compared to 18-day extent by Landsat. However, geostationary satellite imagery is not of much use above 50° latitude, owing to distortion. The authors conclude that operational environmental satellites could be used to create an early warning monitoring system. Gatto (1993) suggests that the synthetic aperture radar (SAR) aboard the European Remote Sensing (ERS) satellite will be capable of providing data on river ice conditions that are necessary for navigating through ice and evaluating the potential for river ice jams and ice erosion along shorelines. He notes two limitations on the use of SAR: resolution prevents showing distinct images on rivers narrower than 30–35 m and on shallow streams with boulders above the water level, and the single band and polarization may limit the differences in ice it can detect. Shokr et al. (1996) report the use of ERS-1 SAR images to monitor sea ice conditions along the east coast of Canada and in the Gulf of St. Lawrence. They found that the images were useful in detecting the difference between ice and open water, but that roughness and other structural information about the ice was not consistent. Further investigation is needed to more fully develop the potential of SAR imagery. ASCE (1995) reports that EarthWatch, Inc., planned to launch a system capable of 3-meter (30-foot) resolution (panchromatic), while systems capable of 1-meter (3-foot) resolution were scheduled by late 1999. If this type of resolution will truly be available, remote monitoring of ice extent would be greatly enhanced, even if imagery would be available on a 2- or 3-week cycle. Computer analysis of this satellite imagery could be highly beneficial, but it is unknown what the processing requirements or acquisition costs may be for such fine resolution.

The processed information would need to be stored in a format that could be read by CADD or GIS users.

(3) *Radar*. A method that may be capable of interpreting ice conditions is that of monitoring active and passive microwaves from an ice surface. Melloh and Gatto (1990a) and Melloh et al. (1991) describe the use of passive microwave imagery to monitor river and lake ice conditions near Fairbanks, Alaska. The imagery was obtained from a Ka-band radiometric mapping system (KRMS) mounted from the bomb bay of an RP-3 aircraft. The KRMS differentiates between wet and dry snow conditions, and open water areas within ice covered rivers and lakes (Melloh and Gatto 1992). Although the KRMS was not able to readily distinguish freezeup ice jams from smooth ice, it could be useful for determining large-scale areal ice coverage. The KRMS also appeared capable of imaging fractures in the ice cover of a lake. Active microwave imagery was obtained with synthetic aperture radar (C-, L-, and P-band) aboard a DC-8 aircraft. Melloh and Gatto (1990a, 1990b) report that active microwave imagery can distinguish between rough and smooth ice covers and detect open water areas within an ice cover. They concluded that the C- and L-bands were better at determining surface roughness. In both instances, the systems tested by Melloh and Gatto were being developed. Each system may be potentially useful in the future, but further refinement of the instrumentation and further investigation into usability in other regions is needed. Additionally, a more convenient and less expensive platform than the RP-3 and DC-8 aircraft is needed.

## 16-9. Systems for Transmitting River Ice Data

An important aspect of data collection that may often be overlooked is the storage and retrieval of data. This section provides a cursory overview of what happens to data once they are collected, including transmission, display, evaluation, and storage. Existing systems are generally adequate for storage needs and will continue to be as computer systems evolve. The first step in storing data is transmitting those data once they are collected, whether they are sent from a DCP site hundreds of miles away or recorded in an observer's notebook across town. The trend is toward remote collection of data to reduce personnel costs and safety hazards. If data are to be remotely collected, this information needs to be transmitted to a central location for storage (and processing). A number of sites are already equipped to do this through the use of DCPs. The use of DCPs in the Corps is covered by policy contained in ER 1110-2-248 and ER 1125-2-308. Data collected at a DCP are transmitted via the Geostationary Operational Environmental Satellite (GOES) Data Collection System (DCS) operated by the National Earth Satellite Service (NESS) of the National Oceanic and Atmospheric Administration (NOAA). The Corps is limited to specific channels for data transmission and all data transmitters must be certified by NOAA/NESS before they are used. All transmission frequencies must be requested first through the Water Resources Support Center, Data Collection and Management Division (WRSC-C). Obviously, a data site cannot be selected and set up overnight if data are to be transmitted from the site via DCP. The use of the GOES/DCS also requires that only environmental data be transmitted; transmission of operational data, such as gate opening, is not allowed.

a. Remote sites may be queried by phone or radio instead of DCP transmission. Information could be downloaded from the on-site data storage device (e.g., a data logger) to a central computer through a modem. This technology has been commercially available for a number of years,

and may prove more feasible and cost-effective as modem speeds continue to increase and phone transmission lines improve in quality. Cellular phones could allow data collection at sites with portable instrumentation or where telephone lines are unavailable. A cellular phone will only be effective, however, where there is adequate cellular coverage; many sparsely populated or rugged terrain areas will not have this. Radios can be used at remote sites for transmitting a warning signal, but radio signals may be susceptible to disruption in heavily populated areas or during severe weather.

b. Data collected manually could be sent to a central site via fax. The fax can be processed on the receiving end by use of optical character recognition (OCR) software in conjunction with a scanner (software does exist that allows a fax to be used as a scanner, but OCR-capability is unknown). While OCR software is quite good at reading typed pages, it fares more poorly with fax documents and even worse with handwritten documents. Eventually, OCR software will be able to handle fax and handwritten documents as well as typed documents.

c. Another possible method of data transmission that has exploded in usage recently is electronic mail, or e-mail. Most e-mail systems allow the sender to attach a file to a transmitted message. The sender and receiver must either use compatible e-mail systems or the sender must be certain that the e-mail system allows the file format integrity to be preserved as it passes through the gateway router. Nonetheless, e-mail allows for simple data transmission, and if a standard form were used, the data could be easily reduced.

d. Data can also be transmitted through the World Wide Web. A password-protected web site can be developed that will allow ice observations to be input directly into a database. The observations are then available to any who query the site. This system is currently used in Nebraska by ice observers (address <http://cavent.nrc.state.ne.us/cgi-win/icejam.exe>). It is expected that this type of data transmission will increase owing to its relatively low cost and high transmission speed.

## 16-10. References

### a. *Required Publications.*

None.

### b. *Related Publications.*

## EM 1110-8-1(FR)

Winter Navigation on Inland Waterways.

## ER 1110-2-248

Requirements for Water Data Transmission Using GOES/DCS.

## ER 1110-2-249

Management of Water Control Data Systems.

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**Melloh et al. 1991**

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